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INDUSTRIAL STERILIZATION
MACHINE vs FISSION PRODUCT SOURCE
COST STUDY

JOB 24-A

Contract: AT(30-1)-850

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Contract: AT(30-1)-850

Date: January 30, 1953

Approved: W. R. Peterson
W. R. Peterson
Project Manager

author on last page

061-001

II

Abstract

A study has been made of the costs of commercial electron accelerators with the objective of estimating the cost of mixed fission product sources when competing with accelerators as a means of industrial sterilization of foods and other products. The assumption was made that the fission product sources would contain highly concentrated fission salts having a specific activity of 10,000 curies per pound. (auth)

To compete with electron accelerators of the minimum and maximum food sterilization rate at two million rep, the costs for equivalent fission product sources are as follows:

Sterilization Rate	Cost per Curie	Cost/lb Dry Fission Product Salts
120 lbs/hr (minimum)	12.1 Cents	$ 1210
2400 lbs/hr (maximum)	4.7 Cents	$ 470

These figures were derived from electron accelerator cost data obtained from the manufacturer of the various machines.

AECU-3557

A brief study has been made with the objective of comparing the costs of electronic accelerators with fission products as sources of nuclear radiation for industrial sterilization of foods and other products. This study was requested by the Washington, D.C. Division of Engineering of the Atomic Energy Commission and has been included as a limited part of Contract AT(30-1)-850.

In the pursuit of this study, discussions were held with the following people who are actively connected with the field of particle accelerators or with the utilization of these devices for industrial sterilization techniques.

<u>Massachusetts Institute of Technology</u>

Dr. Samuel A. Goldblith	Department of Food Technology
Dr. Bernard E. Proctor	" " " "
Dr. Sol Davison	" " " "
Dr. John G. Trump	" " Electrical Engineering
Dr. P. T. Demos	Laboratory of Nuclear Science and Engineering

<u>High Voltage Engineering Corporation, Cambridge, Mass.</u>

Mr. E. Alfred Burrill

<u>Electronized Chemicals Corporation, Brooklyn, N. Y.</u>

Dr. W. Huber

Dr. A. Waly

<u>General Electric Company, Schenectady, N. Y.</u>

Dr. W. W. Schultz	General Engineering Laboratory
Dr. E. L. Mincher	" " "
Dr. Elliot J. Lawton	Research Laboratory (Knolls)
Dr. H. Schreiber, Jr.	X-Ray Division, Milwaukee, Wis.

It has been possible to develop cost information within the scope of the foregoing discussions on Van de Graaff electron accelerators as manufactured by High Voltage Engineering Corporation, Resonant Transformers as manufactured by General Electric Company and the Capacitron as developed by Electronized Chemical Corporation. It is to be pointed out that Van de Graaff accelerators and resonant transformers in various power output ranges are commercially available. An experimental 3 MEV Capacitron is in operation and a 5 MEV industrial prototype Capacitron is under construction at Electronized Chemicals Corporation.

In the strictest sense, no accelerators have as yet been fully engineered for commerical production. The reliability of the accelerators operating under industrial conditions over long periods of time at rated outputs is still unknown. Automatic control systems, and servo systems have not been fully developed for these machines.

Table I of this report includes cost information and performance data for the accelerators. The MIT linear accelerator and the Philips transformer rectifier have been included in view of the potential application of these machines to sterilization of foods and drugs. Specific cost data were not available on these two machines within the time allotted to this study. Two equivalent fission product sources are compared with the accelerators of minimum and maximum product output in pounds per hour. The fission products are assumed to have a specific activity of 10,000 curies per pound at an energy of 0.75 MEV and a calculated utilization efficiency of 17 percent. The cost figures for the fission products are the break even points at which the fission products can compete with commercial accelerators. Sample calculations where necessary for development of Table I are outlined in the appendix.

Table II is a cost breakdown of the cost information listed in Table I.

As an adjunct to Table I, a brief outline of the characteristics of the accelerators is included herewith. In no way is the data in Table I intended to indicate criteria for selecting one accelerator over another.

Van de Graaff Accelerators

This machine is available in a versatile accelerator system which will produce electrons, X-rays, protons, deuterons, tritons, alphas and neutrons. Primary concern in this study is confined to accelerating electrons. The Van de Graaff generator produces intense beams of high energy electrons within a sealed pressurized chamber. Electric charge is sprayed on a high speed insulating belt and conveyed to a hemispherical high voltage terminal which is insulated from the accelerator shell by a compressed gas. Electrons which form the high energy beam are accelerated downward at high velocity via an evacuated tube wherein a potential difference is maintained between the terminal and the lower end of the accelerator. Near the tube exit, the electron beam is scanned by use of magnetic coils so as to cover uniformly a product on a moving conveyer belt. This scanning results in higher utilization efficiency. The degree of electron penetration depends on the accelerating voltage and the density of the target material. Cathode rays penetrate into water about 1 centimeter for each 2 million volts. A monoenergetic electron stream produces its maximum ionization density at a depth below the surface of about 1/3 the maximum range for a stated voltage. In this report machines ranging from 0.5 to 5 MEV are listed, representing a power output range of machines presently or potentially available. The machine manufacturer points out that the existing cost picture of machines would be changed if fission products sources were competing with accelerators. The cost figures in Table I are based on present day prices. Machines which would be engineered for specific food or pharmaceutical sterilization would be considerably lowered in price. These machines can be fabricated for horizontal or vertical installation and can be made portable.

MIT Linear Accelerator

This accelerator was built primarily for nuclear experimentation. Experiments at the Food Technology Laboratories at MIT with this machine at an accelerating voltage of 16 million volts and an average current of approximately 5 microamperes indicate that it is possible, by crossfiring, to penetrate the long dimension of a No. 2 can (3 7/16 inch diameter by 4 9/16" long) containing a luncheon meat pre-inoculated with spores. This machine is not commercially available at the present time but probably could be engineered for industrial sterilization. At present the beam current is quite low. The linear accelerator is about twenty-one feet long. It takes electrons at 2 MEV, injected from a Van de Graaff generator, and accelerates them to approximately 18 MEV, producing a well defined beam of approximately one microampere average current. The wave form is pulsed, a circular wave guide is used which is made resonant by using reflective terminations. This results in a standing wave consisting of traveling waves in the two opposite directions and enables more power to be fed into the cavity.

Capacitron (Electronized Chemical Corporation)

The description and features as reported by the Electronized Chemical Corporation are as follows: Capacitron produces high voltages and great electron intensities during ultra short time periods. A number of capacitors are charged in parallel through resistors in parallel from a rectifier unit. The capacitors are discharged in series by means of gaps which spark over at predetermined voltages.

In the prototype Capacitron, the capacitor banks and discharge tubes are immersed in oil in a separate housing which might be a submerged concrete pool. The pumping equipment, exit window and conveyer belt may be above ground in a separate concrete enclosure. The conveyer belt can also be designed to pass the exit window in a subterranean well to take advantage of the earth for shielding. The spark gaps are sealed in a compressed gas. Magnets are used to bend the beam of electrons around for adaption to conventional conveyer belts. This machine operates at 5 MEV. The energy per pulse is 1.5×10^9 Rep grams. The intensity of each pulse is in the order of kiloamperes in about 2 microsecond periods. One pulse takes place every two seconds. The process sterilization rate will be about one thousand pounds per hour of material of unit density on the basis of commercial sterility (10^{-8} organisms per gram or one failure per one million grams per 100 gram packages.) It is contended by the designers, that electrons delivered in microsecond bursts at high voltages are not apt to cause flavor changes. Results of experiments with the Capacitron are claimed to contradict the so called "target theory" of radiation dose which postulates that there is no difference between a high intensity dose in a short exposure time and a low intensity dose over a longer exposure period.

Resonant Transformer, General Electric Company

Machines of 1 and 2 million volts at 3 milliamperes are available. A 3 million volt machine with an output current of 10 ma. is being developed. The 1 MEV machine consists of a low frequency resonant transformer, with a coaxially mounted multi section sealed off X-ray tube. These components are housed in a pressurized tank containing freon. The twelve section x-ray tube, electron emitting cathode is a copper backed tungsten target mounted in the lower end of the extension chamber. The wave form is continuous (half wave rectifier) with a frequency of oscillation of 180 cycles per second. There are no moving parts and no iron core is necessary. The machine may be designed for vertical or horizontal installation. The beam may be scanned for greater utilization efficiency.

Transformer Rectifier-Philips Co. (of Holland)

The 1.4 MEV Machine is a seven stage voltage - multiplier with a 3 milliampere output current. It consists of a generator, smoothing column and accelerator tube. The circuit contains nineteen mercury rectifiers. The capacitors in the multiplying circuit form a loop with two principal capacitors and three choke coils and thus feed high frequency power to the top of the generator and down again. A smoothing column of capacitances reduces ripple and supplies D-C voltages to the seven stage accelerator tube. The accelerator tube system has a low x-ray background since the small lens apertures prevent secondary electrons travelling up the tube from gaining more energy than is imparted per stage. The cylindrical lens shield prevents it from viewing the walls of the tube. The beam enters a target room and is turned 90 degrees by a magnet. Double focusing of the beam is possible.

Fission Product Source

Two sources consisting of multiple rods 2 cm. diameter by 15 feet long with a total curie source strength equivalent in production rate to the accelerators of minimum and maximum output have been listed in Table I for comparison with the accelerators. These rods would be arranged on a 60 degree pitch with sufficient clearance between rods to process material of unit density to a radial distance of one mean free path (the reciprocal of the absorption coefficient) at about .75 MEV and a calculated utilization efficiency of 17 percent. The rods contain fission product salts with an assumed density of 4 grams per cc and a specific activity of 10,000 curies per pound. These sources would require shielding of about 3.5 feet to 4 feet of concrete and could be telescoped into the earth when not in use.

Comparison of the Physical Features of Electron Accelerators with Fission Product Sources

Some of the relative advantages of electron accelerators over fission products and vice versa are listed as follows:

1. The accelerators may be turned on or off at will, a feature not possible for fission product source.

2. Cathode rays from the accelerators depend on the magnitude of the accelerating voltage and have a definite penetration range into material. This range is much less than for gamma rays of equivalent potential. Thicker materials may therefore be sterilized with fission product sources than is possible with the accelerators. However, it is possible to crossfire the electron beams to increase the penetration range of the accelerators. Wide samples may be treated with cathode ray beams by using electromagnetic scanning techniques.

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3. Conventional food containers, now used by canners, are for the most part, too large in size for electron penetration, at energies now readily available by particle accelerators. Fission products provide a source of gamma radiation which do have sufficient penetration.

4. Accelerators are best used to treat materials moving on a conveyer belt because of the ability to control the beam energy. Fission product sources are best used for batch systems wherein a product can surround the source so as to use the entire radiation field of the source. This appears to be the case because of the present conveyer belt installations in the food industry. Fission product source are adaptable to screw conveyers and Redler conveyers.

5. Replacement of the fission product source will depend on the half life of the source. The source assumed for this report is expected to have a half life of 2 1/2 years. The principal replacements for the accelerators are the electron tubes and charging belt, each having a life of about 1000 hours.

6. The bulk shielding requirements for fission product sources are higher than for electron accelerators.

7. Fission product sources require no electrical installation for activation of the source.

8. Mixed fission product sources require a high degree of concentration to produce salts of high specific activity from present waste streams.

<u>Cost Comparison Basis</u>

The cost figures as tabulated in Table I were based on the following assumptions:

1. The plant and equipment would be amortized linearily over a 5 year period.

2. The plant would operate an average of 20 hours per day, 300 days per year.

3. Electrical power is available at $0.01 per KWH.

4. One man per shift required for machine operation. One-third men per shift required for maintenance and health physics. (total:-4 men per 24 hr. day).

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5. The fission product source has a half-life of 2 1/2 years, therefore requiring 2 charges during the 5 year period, and a calculated utilization efficiency of 17%.

6. No salvage value is assumed as credit after the 5 year period.

7. No dollar credit has been taken for the fission product source for the net savings in storage facilities which would be realized if all the wastes were directly converted to useful sources.

8. The dollar value of the fission product source shown in Table I would be the value as delivered to the user.

9. No charge has been included for overhead on any of the machines, nor on fission products.

Summary

Electron accelerators though commercially available have not as yet been fully engineered for industrial sterilization of foods and other products. Van de Graaff generators and resonant transformers in various energy ranges are presently available. The Capacitron can be made on specific request pending arrangements for commercial production. Of the accelerators studied, the 18 MEV MIT linear accelerator produces cathode rays having a depth penetration approaching penetrations possible with fission product sources. This accelerator is not commercially available at present.

The costs per curie and costs per pound of dry fission product salts for fission product sources have been estimated based on an equivalent production output for accelerators of the minimum and maximum sterilization output. Assumptions were made that such sources would be small diameter rods containing mixed fission product salts having a specific activity of 10,000 curies per pound and a calculated utilization efficiency of 17 per cent.

To compete with an electron accelerator having a minimum production rate of 120 pounds per hour, the estimated cost per curie is about 12.1 cents or $1,210 per pound of fission product salts. To compete with an accelerator of a maximum production rate of 2400 pounds per hour, the estimated cost per curie is about 4.7 cents or $470 per pound of fission product salts.

TABLE OF SYMBOLS

A	=	Distance from edge of source to object receiving radiation, cm
B	=	$\mu A + \nu Z$ for cylinder source
C	=	Source strength, curies
Cv	=	Curies per unit volume
D	=	Dose rate, Rep/sec.
K	=	Conversion Constant
L	=	Length of source, cm
R	=	Radius of source, cm
V	=	Volume of source cu. cm
Z	=	Self absorption dimension for cylinder source, cm.
μ	=	linear absorption coefficient of irradiated material cm^{-1}
ν	=	linear absorption coefficient of source material cm^{-1}
θ	=	half angle from source to object

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References

1. A. E. C. Project Handbook CL-697 Chapter V
2. High Voltage Engineering Technical Bulletin D-1
3. KLX-24 (AT-30-GEN-169)

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Appendix

Sample Calculations:

Fission Product Source:

1 million curies
8 rods 2 cm. dia. x 15 ft. long
Rods contain mixed fission product salts assumed specific activity 22 curies/gm
Density of salts 4 gm/cc (Assumed)
Mean gamma ray energy 0.75 Mev (Assumed)
Linear absorption coefficient of fission product salts $\nu = 0.3\ cm^{-1}$ (Assumed)
Linear absorption coefficient of irradiated material, $\mu = .074\ cm^{-1}$
Density of irradiated material 1.0 g/cc
Note: Material of unit density being irradiated by surrounding each rod to a distance of one mean free path $(\frac{1}{\mu} = 13.5\ cm.)$

Weight of unit density material being irradiated per unit rod:

$= (14.5)^2 \times (15 \times 30.4) - (1)^2 (15 \times 30.4)$

$= 3 \times 10^5$ gms

Total wgt. for 8 rods: 5300 lbs.

Refer to table of symbols:

$$\bar{D} = \frac{C_v R^2 K}{2(A+Z)} f(\bar{\theta}, \bar{B})$$

Reference (1)

$\mu R = 0.3 \times 1.0 = 0.3$
$\nu Z = 0.16$ Fig 5 Reference 1

$\theta = 70^\circ - 90^\circ$ $Z = 0.5$
$\mu A = 1.00$ $A = 13.5$

$\bar{B} = \mu A + \nu Z = 1.16$

$f(\bar{\theta} \bar{B}) = f\ (80^\circ, 1.16) = 0.27$ Fig. 1 (Reference 1)

$$K = .074\ cm^{-1} \times 3.7 \times 10^{10} \frac{Dis.}{Sec.\ Curie} \times .75 \frac{Mev}{Dis.} \times 10^6 \frac{ev}{Mev} \times \frac{1}{32} \frac{Ion\ Pairs}{ev} \times 6.2 \times 10^{-13} \frac{Rep\ grams}{Ion\ Pairs} = 39.7$$

$C_v = 22 \times 4 = 88$ curies/cc

Time to achieve 2 million rep. dose

$$= \frac{2 \times 10^6}{33.5 \times 3600} = 16.6 \text{ hours}$$

$$\text{Process Rate} = \frac{5300}{16.6} = 320 \text{ lbs/hr}$$

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Kilowatt Equivalent of Source at 0.75 Mev:

$$1 \times 10^{6} \text{ Curies} \times 3.7 \times 10^{10} \frac{\text{Dis}}{\text{Sec} \times \text{Curie}} \times 0.75 \frac{\text{Mev}}{\text{Dis}} \times 1.6\times10^{-6} \frac{\text{Ergs}}{\text{Mev}} \times 10^{-7} \frac{\text{Watt-Sec}}{\text{Ergs}}$$

= 4450 Watts
4.45 KW

Utilization Efficiency of Source:

Basis 93 ergs per gram of water
1 rep = 42,100 ergs per pound
= 2.64×10^{10} Mev
for 2 million rep. dose = 5.26×10^{16} photons
at 0.75 Mev:

$$\frac{5.26 \times 10^{16}}{0.75} = 7.04 \times 10^{16} \text{ photons}$$

for 1 lb. in 6×10^{4} seconds residence time

$$\frac{7.04 \times 10^{16}}{6 \times 10^{4}} = 1.17 \times 10^{12} \text{ photons/sec}$$

$$\frac{1.17 \times 10^{12}}{3.7 \times 10^{10}} = 31.8 \text{ Curies per pound sterilized}$$

for 5300 lbs:
31.8 x 5300 = 1.69×10^{5} Curies

$$\text{Utilization Efficiency} = \frac{1.69 \times 10^{5} \times 100}{1 \times 10^{6}}$$

= 16.9%

Fission Product Source:

Shielding Requirements:
Assume 8 rods of 125,000 curies each are equivalent to 1 rod 2 cm. dia. of 1 million curies.

Dose in air

$$D = \frac{C v R^{2} K}{2(A + Z)} f(\theta B)$$ Reference (1)

$\mu A = 0$
$\sqrt{R} = 0.3$
$\sqrt{z} = .18$ Figure 5 Ref. 1
$z = .6$
$\theta = 90^{\circ}$

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Appendix (cont'd)

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$f(\theta B) = f(90^\circ, 0.18) = 1.05$ Figure 1 Ref. 1

$$K = 3.5 \times 10^{-5} cm^{-1} \times 3.7 \times 10^{10} \frac{Dis}{Sec \times Curie} \times 0.75 \frac{Mev}{Dis} \times 10^{6} \frac{ev}{Mev} \times \frac{1}{32} \frac{ion\ pairs}{ev} \times 4.8 \times 10^{-10} \frac{Roentgen \times cc}{ion\ pairs}$$

$K = 14.6$

$$D = \frac{88 \times 1.0 \times 14.6 \times 1.05}{28.2} = 48 \text{ R/sec}$$

$Io = 48 \times 3600 \times 1000 = 1.73 \times 10^{8}$ Mr/hr

Assume Build up Factor for Secondary Radiation = 1.5
Let I, tolerance level = Mr/hr

$$B \times \frac{Io}{I} = 1.5 \times 1.73 \times 10^{8} = 2.58 \times 10^{8}$$

Shielding

Absorption coefficient for concrete at 0.75 Mev = .406 in^{-1}

from figure .04 of reference 3

t = 45" concrete (approximate)

Sample Calculations for Accelerators:
Van de Graaff 3 million volt, 3.3 ma machine

Power Output:
$$KW = \frac{3 \times 10^{6} \text{ volts} \times 3.3 \text{ ma}}{10^{6}} = 10 \text{ KW}$$

Production rate for unit density material at 50% utilization efficiency
2 million rep = 7.6 KW - Sec/lb.

$$\frac{10 \times 3600 \times 0.50}{7.6} = 2400 \text{ lbs/hr}$$

Penetration Reference (2)

3 Mev Van de Graaff from one side is 0.5" for density = 1 g/cc effective thickness
Assume target material has an effective thickness of 1.03 g/cm^2 Exit Dose = 0.33 g/cm^2/Mev
Incident Electron = $\frac{1.03}{.33}$ = 3.1 Mev
Beam from both sides = 1.5 Mev

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TABLE I

COMPARISON OF COMMERCIAL ELECTRON ACCELERATORS WITH FISSION PRODUCT SOURCES FOR INDUSTRIAL STERILIZATION OF FOODS AND OTHER PRODUCTS

Accelerator Type	Van De Graaff Electron Accelerator				Resonant Transformer			Capacitron	Linear Accelerator	Transformer Rectifier	Fission Products	
Manufacturer	High Voltage Engineering Corporation				General Electric Company			Electronized Chemical Co.	M.I.T.	Philips Co. (Holland)	-	-
Voltage (mev)	2	0.5	5.0	3.0	1	2	3	5	18	1.4	0.75	0.75
Electron Current (ma)	0.25	2.0	0.5	3.33	10 (5)	10 (5)	10 (5)	(Burst 50,000 amp)	3-5 μa avge 30-100 ma peaks	3	3.4×10^5 C	6.8×10^6 C
Power Output (KW)	0.5	1.0	2.5	10.	2.5	5	7.5	$\approx$ 12		42	1.5	29.8
Penetration: Basis Sp Gr = 1.0												
From one side (in.)	0.3	0.05	0.8	0.5	0.16	0.3	0.5	0.7	ca. 2	0.23	5.4	5.4
From Both sides (in.)	0.7	0.12	1.9	1.1	0.35	0.7	1.1	1.6	ca. 4.6	0.5		
Output Beam Form	----------- Continuous -----------				(Continuous Half Wave Rectifier)			Surge (3)	1 μsec pulse, 120 cps	continuous ripple	Continuous field	Continuous field
Space Requirements	10' x 10' x 12' H	15' x 15' x 25' H	20' x 20' x 40' H	25' x 25' x 45' H	10' x 10' x 12' H	15' x 15' x 20' H	20' x 20' x 25' H	13,000 gal Approx. 10' x 20' x 10' H	10' x 25' x 15' H	40' x 25' x 9' H	5' x 5' x 30' H Above Ground 3' x 3' x 25' Below ground ca. 3.5 concrete	7' x 11' x 30' H Above Ground 7' x 11 x 25' H Below ground ca. 4' concrete (shield)
	Radiation Room Below-9' H	Radiation Room Below-9' H	Radiation Room Below-9' H	Radiation Room Below-9' H	Radiation Room-9' H	Radiation Room-9' H	Radiation Room 9' H		9' High Adjacent Radiation Room	9' H Radiation Room		
Initial Cost of Machine (1)	$80,000	$150,000	$250,000	$400,000	$75,000	$175,000	Costs Unavailable	$250,000	Costs Unavailable	Costs Unavailable	$82,500	$172,800
Total Initial Capital Cost	$129,000	$220,000	$350,000	$545,000	$122,500	$252,500	-	$350,000	-	-	$120,000	$746,000
Gross Product Treatment Rate at 50% Beam Eff. (lbs/hr)	120	240	600	2,400	590	1,180	1,770	1,000 (4)	-	-	120	2,400 (utilization Eff 17%)
Cost of Sterilization (cents/lb (2))	7.5	5.5	3.2	1.2	1.6	1.3	-	2.0	-	-	7.5	1.2
Cost of fission products - (cents/C)	-	-	-	-	-	-	-	-	-	-	12.1	4.7
Cost per pound of Dry Fission Product Salts (10,000 C/lb - Density 4 g/cc)	-	-	-	-	-	-	-	-	-	-	$1,210	$470

(1) Not including installation, instrumentation & auxiliaries
(2) Bases 5 year amortization - 6,000 operating hours, including personnel & maintenance
(3) 1 pulse/2 sec, 2 micro seconds per pulse, 1.5×10^9 rep gms.
(4) Commercial sterilization (Defined by Electronized Chemicals Co. As 10^{-8} organisms/g)
(5) Peak

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TABLE II

COST BREAKDOWN OF ELECTRON ACCELERATORS AND FISSION PRODUCTS

Source	Van De Graaff Generator				Resonant Transformers (General Electric Co.)		Capacitron	Fission Products(3) 3.4×10^5C	6.8×10^6C
Mev Output	2	0.5	5	3	1	2	5	0.75	0.75
KW Output	0.5	1.0	2.5	10	3	8	~12	1.5	29.8
Initial Cost of Machine ($)	80,000	150,000	250,000	400,000	75,000	175,000	250,000	82,500	642,600
Building & Shielding ($25,000 + 20% of Machine Cost) ($)	41,000	55,000	75,000	105,000	40,000	60,000	75,000	33,250	89,300
Installation, Instrumentation & Auxiliary Equipment (10% of Machine)	8,000	15,000	25,000	40,000	7,500	17,500	25,000	4,250	32,100
Total Initial Investment ($)	129,000	220,000	350,000	545,000	122,500	252,500	350,000	120,000	764,000
Cost Per Year (5 Year Amortization) ($)	25,800	44,000	70,000	109,000	24,500	50,500	70,000	24,000	152,800
Replacement Cost (10% of Machine Per Year)	8,000	15,000	25,000	40,000	7,500	17,500	25,000	(2)	(2)
Power Costs $0.01/KWH (25% Efficiency)($)	120	240	600	2,400	2,400	4,800	2,880	-	-
Operators (4 at $5,000/yr) ($)	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Total Yearly Cost($)	53,920	79,240	115,600	171,400	54,400	92,800	117,880	54,000	172,800
Material Sterilized (2 Million Rep. lbs/hr)	120	240	600	2,400	590	1,180	1,000 (1)	120	2,400
Sterilization Cost (cents/lb)	7.5	5.5	3.2	1.2	1.6	1.3	2.0	7.5	1.2
Estimated Cost of Fission Products Cents/C Dollars/lb. (10,000 C/lb.)								12.1 1,210	4.7 470

(1) Basis Commercial Sterility (Defined by Electronized Chemicals As 10^{-8} organisms/g)
(2) Included in Initial Cost
(3) Two Sources Required in 5 Year Period

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Report prepared by:

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Research Supervisor

Fahnoe

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